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# THE USE OF HYDRAULIC MODELS IN THE DESIGN OF SUSPENDED-LOAD SAMPLERS

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Introduction and analysis of problem--The amount of suspended solid material transported by a stream is usually determined by making measurements of sediment-content and of velocity at many points in the cross-section and integrating the results. The number of sampling points required will depend upon the degree of accuracy necessary, and, according to O'Brien [see 1 of "References" at end of paper], upon our knowledge of turbulent flow and its relation to sediment-transportation.

The suspended-load samplers used for these measurements may be divided into two classifications, depending upon the length of the sampling period. One might be called the integrating or continuous sampler, and the other the instantaneous or grab sampler. Turbulent fluctuations cause the sediment-content at any point in a stream to be continually varying; therefore, only an integrated sample, taken over a period of time long enough to get an average concentration, can truly represent the sediment-content. This integration may be made with a continuous sampler of the suction-nozzle type, which maintains the same velocity at the entrance as the undisturbed velocity of the stream at that point. (Continuous suction-nozzle samplers are now being used in the Cooperative Laboratory of the Soil Conservation Service at the California Institute of Technology.) The mean concentration may also be obtained by combining a number of small grab-samples which show the true instantaneous sediment-content.

Disturbances caused by the sampler will produce changes in the local concentration that vary with the particle-size and distribution. Small changes may be expected when the sediment is fine and uniformly distributed, but larger ones should result when the particles being transported are coarse and the distribution non-uniform. Redistribution of sediment takes place whenever an obstruction causes a stream-filament to deviate from its undisturbed path. In the resulting curvilinear flow, materials having a density greater than water will be accelerated less rapidly and will follow a path with larger radius of curvature. When this occurs, that is, when silt and water at any point are following different paths, redistribution is taking place.

Criterion for comparing samplers--From the above analysis it is apparent that the most representative sample will be obtained when we have the least disturbance to the sampled fluid before it is taken. Therefore, we may judge the merits of a sampling device by the degree to which it meets the conditions set forth in our criterion for the ideal. This requires that no portion of the sampled fluid shall be disturbed by changing its normal velocity, in either magnitude or direction, before it arrives at the point where it is taken. Any sampler will cause some disturbance; therefore, we may evaluate the relative accuracy of such instruments by devising some means of determining the deviation from the ideal.

Hydraulic test-methods--It would be a simple matter to determine by direct test the efficiency or reliability of a sampler if the sediment-concentration at a point in a stream were known. Unfortunately the only means at hand to determine the concentration involves sampling and at once reduces direct tests to a comparison of instruments and techniques. Furthermore, comparing the sediment caught by various instruments is misleading because the character of both the turbulence and the available sediment in the stream or flume affect the results. The practical difficulty of either directly testing or comparing samplers leads to the consideration of other methods of evaluating the performance of such devices. One method that we believe gives an indication of the absolute accuracy, rather than a comparison between samplers of unknown accuracy, is based upon the preceding flow-analysis by which we developed the criterion.

Since the criterion does not permit any disturbance, it becomes necessary to determine the deviation from the ideal; and this can be done by observing the paths of dye-streams injected into the flow. Consequently, in the testing procedure, sampler models were supported in a glass-walled flume and dye-streams were injected upstream at suitable points for observing the disturbance to the filament of fluid entering the sampling space. It seems logical to conclude that there will be no redistribution of sediment if the dye-streams, which follow the flow perfectly, show that no disturbance occurs.

Selection of samplers for testing--After studying various samplers and considering our immediate needs, two types of grab-samplers were selected for hydraulic tests because they seemed most promising for development into instruments that produce little disturbance. One, the horizontal-tube type, consists of a cylindrical or prismatic tube that can be closed to trap a portion of the fluid. The other, the cutter-type sampler, traps a cylinder of fluid between two sealing disks when a spring-actuated cutter tube slides over one disk and strikes the other. The latter type was first used by the late Henry M. Eakin [2] in studying suspended load in the Mississippi.

Hydraulic tests of the Eakin cutter-type sampler--Figure 1 shows one unit of the original Eakin cutter-type suspended-load sampler. A comparison of this sampler with many others indicates that it would cause less disturbance to the flow of the sampled fluid and thereby more nearly satisfy the criterion for the ideal. Those types that do not allow free and undisturbed circulation through the sampling space cannot comply with the criterion.

Figure 2 shows a view looking down into the flume where the hydraulic models were tested in nine inches of water which had a velocity of about three-quarters of a foot per second. The milk

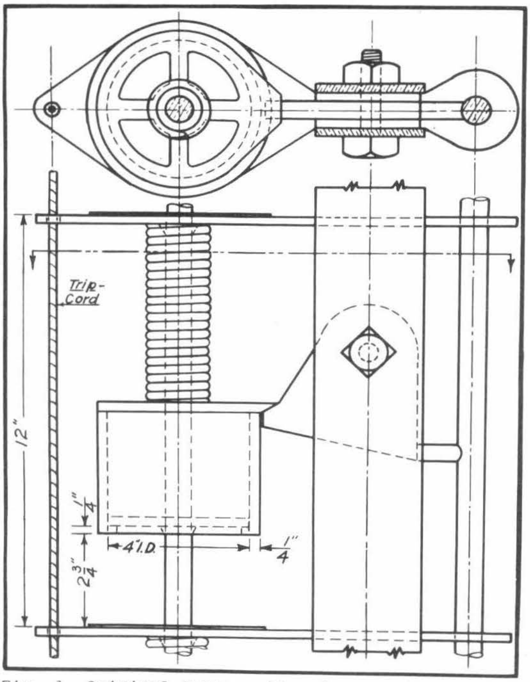



Fig. 1--Original Eakin cutter-type suspended-load sampler

bottle above the observation window supplied the dye that was injected through a small tube at points located directly upstream from the center-line of the models and at vertical intervals of one-quarter of an inch. In the foreground one of the sampler models is shown in place ready for a test in which the paths of the dye-streams, as seen from the flume-window, were drawn in relation to the sampler models.

It was evident that the interference to the flow caused by the original Eakin sampler

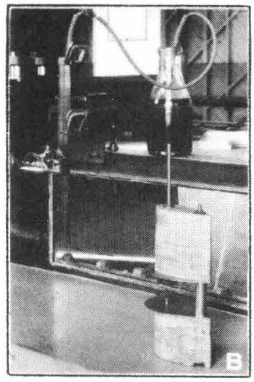



Fig. 2--Equipment for testing suspended-load samplers by observing disturbance to filament of fluid entering sampling-space

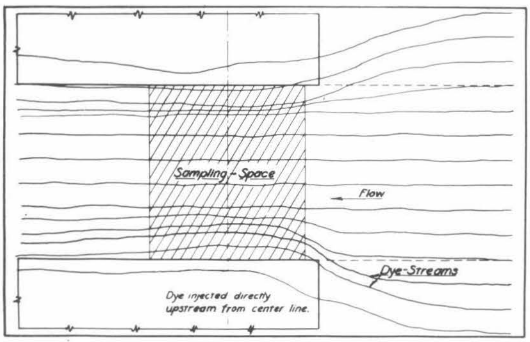



Fig. 3--Plot of stream-lines showed curved flow caused by the sampler-body

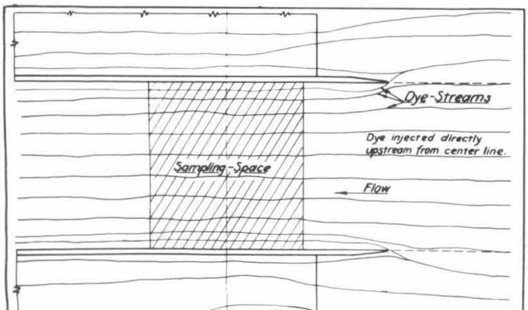



Fig. 4--Stream-line plot showing plates for decreasing curvature of flow

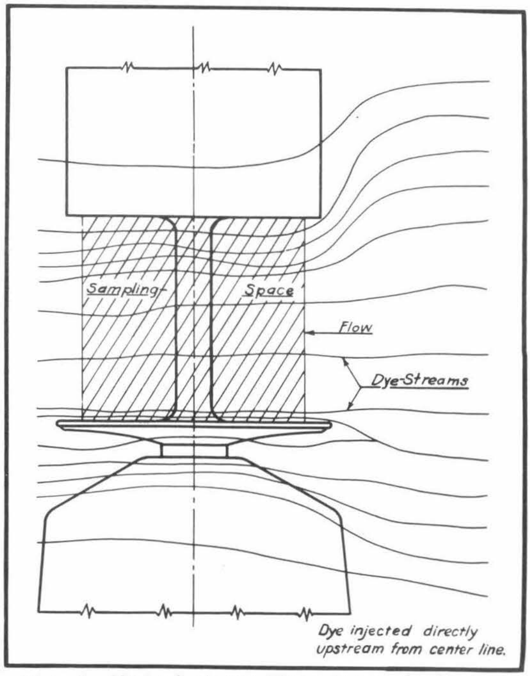



Fig. 5--Plot of stream-lines for a single-unit suspended-load sampler

could be greatly reduced by removing the trip-cord, eliminating a recess at the top of the sampling space, using a thin cutter-tube, and removing the rod from the center of the sampling space by supporting the mechanism from the rear with a stream-lined housing. A wooden model with outside dimensions conforming to these changes was used in the first run. A study of the resulting flow-pattern revealed the desirability of an additional modification which was incorporated in the model for the second test. The stream-line plots from these tests may be compared in Figures 3 and 4. The upper figure shows clearly that the high-pressure area in front of the body causes the flow to curve toward the sampling space. The lower figure shows that this tendency was decreased when the model was modified by extending thin plates upstream and to the sides (see plates in Fig. 2) so that the body-sections were isolated from the sampling space.

A study of these flow-pictures suggested the possibility of sampling only the least-disturbed part of the space between the plates by isolating the central portion between thin disks (see plates and disks in Fig. 2). Model-tests indicated that this was better than using the plates alone, but the improvement in the flow-pattern was not considered sufficient to warrant the more complicated construction.

Single-unit samplers that are supported in the stream by means of a line were constructed during these studies. Figure 5 shows that the stream-lines around one of these have very little cruvature at the bottom of the sampling space but are quite curved at the top. Flow-correcting plates were not used, however, because a line-suspended sampler will drift and assume an angle to the flow so that their advantages cannot be fully realized. We should not conclude that tilting the sampler has sacrificed the advantages of the cutter-type construction because, with bad orientation, flow through the sampling space is not impaired to the extent that it would be in other types which have a sampling space less accessible to the flow.

Hydraulic tests of the horizontal-tube sampler--The other samplers that were tested with hydraulic models were of the horizontal-tube type. Instruments of this kind have been used that employed gate-values or standard check-valves at the end of 1-inch to 1-1/4-inch-diameter pipe, the valves being spaced 12 to 14 inches apart. The internal resistance of a long, slender tube makes it impossible for the flow-conditions to be unchanged as water passes through it. The lower velocity inside the tube may cause deposition of the coarse particles, and the change in velocity at the entrance will cause some sort of redistribution of the sediment. Because of such undesirable flow-conditions, samplers using long, slender tubes were not considered satisfactory and consequently they were not tested.

A shutter-mechanism consisting of a plug valve, which traps a portion of water inside the plug, would permit the use of a short tube with a large diameter. For a multiple-unit sampler the horizontal tubes could be placed, one above another, at the desired intervals. With the tube-supporting member of the same size as the plug-valve housing, the tendency would be for more than the normal amount of water to be forced through the tube. However, the internal friction of the tube would oppose this tendency and could be made to exactly balance it by adjusting the tube-length.

Figure 6 shows one of the wooden hydraulic models used in testing the flow-conditions around horizontal-tube samplers. The position and length of the tube could be varied. In the testing procedure a single dye-injector was supported 2-1/2 inches upstream from the entrance of the tube, and the injector adjusted vertically and across the flume until the dye-stream was split by the wall of the tube, one-half going inside and one-half outside. A number of these injection-points which permitted the dye-stream to be divided, were found and located with respect to the axis of the tube. Plots of these readings gave the cross-sectional area, 2-1/2 inches upstream from the sampler, of the stream-filament entering the tube. Changes were made in the sampler-design in order to make the cross-section of the stream-filament equal to the cross-sectional area of the tube.

In the first series of tests a 2-1/2-inch inside-diameter tube was mounted in the 4-1/2-inch cylindrical body shown in Figure 6, and also in a 4-1/4 by 9-inch stream-lined body. The nose-length was kept constant at two inches while the total tube-length was varied from 11 to 15 inches. Plots of the cross-section of the stream-filaments which entered the sampling space showed that, due to some instability that existed for long tubes, changing the length between these limits did not produce a progressively decreasing filament-area.

The plots of all the filament-areas in this run were elongated because the body affects the entrance conditions. Measurements of the filament-elongation for various nose-lengths showed the elongation to be less when the entrance was farther from the body; consequently, the nose-length was increased to one tube-diameter for the final run. The stream-lined body was not used because erratic conditions prevailed with the long tube-lengths required.

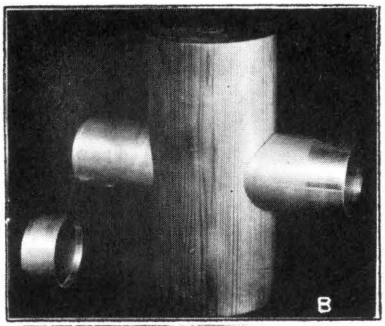



Fig. 6--One hydraulic model used in testing flow-conditions around a horizontal-tube sampler

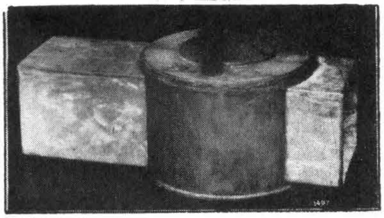


Fig. 8--Hydraulic model of horizontal tube sampler that uses square tube and short shutter-housing

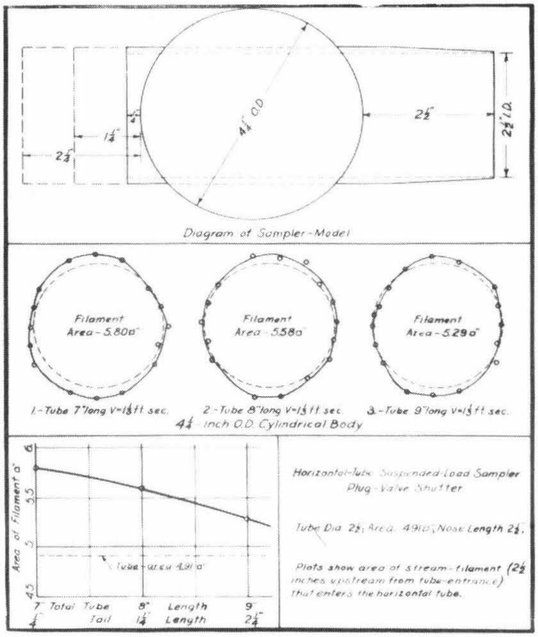



Fig. 7--Test-data for cylindrical-body horizontal-tube sampler for three tail-lengtns

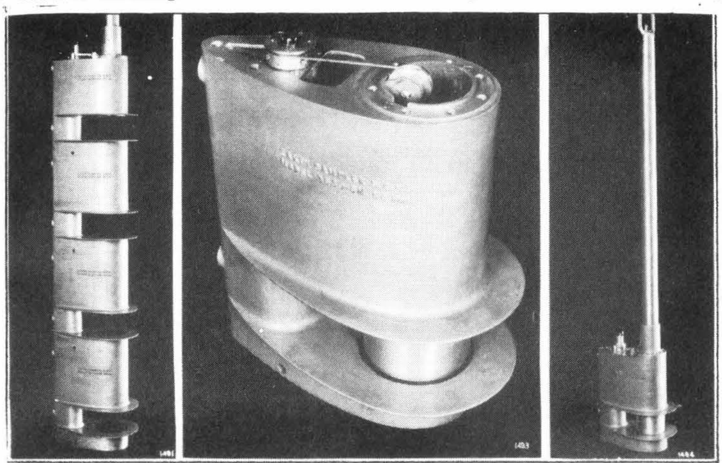


Fig. 9--Close-up view (center) of one unit of later design of multiple-unit Eakin suspended-load sampler; stack (left) of these units arranged for taking samples at vertical intervals of one foot; single unit (right) with supporting rod and shutter-operating mechanism

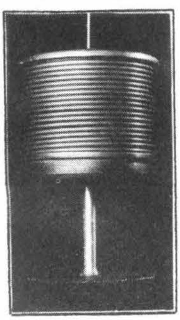
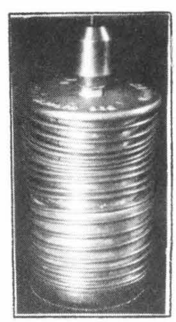


Fig. 10--Single, portable, compact instrument of Eakin type that may be lowered into stream with a line to sample solid material in suspension; open position (left); closed position (right)



The final run was made with the 2-1/2-inch inside-diameter tube in the 4-1/4-inch cylindrical body. The nose-length was adjusted to one tube-diameter and the tail-length was varied by using tube-extensions to produce changes in the filament area. Results are recorded in Figure 7 and they indicate that the filament-area decreases with increasing tube-length. By extrapolation it appears that a tail-length of about 3-1/4 inches would give a filament with an area equal to that of the tube cross-section. However, a longer nose-length would possibly be better since it would put the entrance farther from the disturbed area and reduce the required total tube-length. Before horizontal-tube samplers are constructed, more detailed investigations along these lines should be conducted, using the exact dimensions of the proposed designs.

In the above tests the body-sections between the horizontal tubes had the same size as the plug-valve-shutter housing in order to provide sufficient stiffness for a stack of samplers held rigidly at one end. If a body-section only long enough to enclose the shutter-mechanism is employed, the smaller size will reduce the high-pressure area in front of the body and the low-pressure area behind it. This will make it possible to use shorter tube-extensions and thus produce a sampler that causes less disturbance to the normal flow. A rotary, barrel-type shutter might be used to avoid possible objections to rotating the alignment of the sampling space, as is done in closing the plug-valve sampler; and a square tube could be used in order to secure the largest sample possible in relation to the size of the shutter-housing. These changes would result in a design similar to Figure 8. Tests of this model showed that the plot of the stream-filament cross-section had an area smaller than that of the tube. This indicated that the tube-extensions could be made much shorter--possibly no extension at all behind the body. Due to the anticipated difficulty in producing a sampler of this type that would operate satisfactorily in silt-laden water, further tests were not conducted.

Mechanical design of a multiple-unit sampler--A request of the Hydrologic Division of the Soil Conservation Service for an instrument designed to take sumultaneous samples at vertical intervals of one foot or more brought about the development of the apparatus shown in Figure 9. The one-piece aluminum-alloy housings (center) are bolted together to form a multiple sampler (left) that weighs nine pounds per unit. The bottom plate, rod-adapter, and tripping mechanism (right) were used to test the sampler for proper operation in heavy concentrations of fine sand. It is believed that the end-sections could be used when samples are taken from low bridges or when sampling shallow streams by wading. Handling facilities should be designed to suit the sampling station when more than two units are stacked together, when the water is deep or the velocities high, and when high structures traverse the stream.

Mechanical design of single-unit line-suspended samplers--After an experimental single-unit line-suspended sampler was constructed, a second design was developed which was satisfactory for certain sampling stations. However, it had excessive drift in high-velocity streams and its construction was believed to be more complicated than necessary.

The sampler shown in Figure 10 was designed to overcome these difficulties by reducing the size and frontal area and by increasing the weight. This was accomplished by using a more compact arrangement of parts, using a small supporting cord, constructing the working parts of bronze, and putting the spring on the outside so that the interior could be filled with lead. Any further material increase in compactness is impossible since the top of the sampler is only about one-eighth of an inch above the active portion of the cutter-tube. The weight of the instrument as shown is 6-1/2 pounds which is sufficient for many sampling stations. In high-velocity streams where drift becomes excessive, a stream-lined weight may be attached in place of the cap-nut at the bottom.

Although this design is applicable to any sample volume, the half-pint size illustrated is recommended so that, in low-velocity streams where additional weights are not necessary, it may be handled by some convenient means such as a swordfish line and reel. When the required accuracy demands a larger volume for laboratory analysis, a number of samples may be taken and combined. Accurate results will require this, regardless of the size of the sampler, in order to average the fluctuations in concentration due to turbulence.

Conclusions--Experiments have shown that satisfactory samplers may be built of both the cutter type and horizontal-tube type, provided design-principles based upon properly conducted flow-studies are observed. After making an analysis of sediment-laden flow and studying the results of flow-pattern investigations, it was concluded that the Eakin cutter-type sampler could be made to approach more closely the conditions set forth in our criterion for the ideal, and therefore it was selected for the development of improved mechanical designs.

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References

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